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AIR FORCE MACHINABILITY DATA CENTER
Cincinnati, Ohio 45209

MACHINING DATA FOR BERYLLIUM METAL

AFMDC 66-3

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AFMDC 66-3

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JUNE 1966

Advanced Fabrication Techniques Branch
Manufacturing Technology Division
Air Force Materials Laboratory
Research and Technology Division
Air Force Systems Command
United States Air Force
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AFMDC 65-2	FIRST ANNUAL REPORT OF THE AIR FORCE MACHINABILITY DATA CENTER, FEBRUARY 1966, AD-482 278
AFMDC 66-1.1	MACHINING DATA FOR NUMERICAL CONTROL - TURNING, JUNE 1966, AD-483 994
AFMDC 66-2	GRINDING RATIOS FOR AEROSPACE ALLOYS, JUNE 1966, AD-483 995
AFMDC 66-3	MACHINING DATA FOR BERYLLIUM METAL, JUNE 1966

DATA PRODUCTS IN PREPARATION:

AFMDC 66-1.2	MACHINING DATA FOR NUMERICAL CONTROL - FACE MILLING
AFMDC 66-1.3	MACHINING DATA FOR NUMERICAL CONTROL - DRILLING
AFMDC 66-1.4	MACHINING DATA FOR NUMERICAL CONTROL - PERIPHERAL END MILLING
AFMDC 66-1.5	MACHINING DATA FOR NUMERICAL CONTROL - END MILL SLOTTING
AFMDC 66-1.6	MACHINING DATA FOR NUMERICAL CONTROL - TAPPING
AFMDC 66-1.7	MACHINING DATA FOR NUMERICAL CONTROL - REAMING
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INTRODUCTION

Within the past several years there has been an increasing effort toward developing beryllium as a fully acceptable structural material. Recent improvements in strength obtained from forged and extruded beryllium have stimulated new design considerations. In turn, new designs have created a need for additional technology in all areas of fabrication, including machining.

An increasing number of inquiries to the Air Force Machinability Data Center for beryllium machining information plus a scarcity of data compiled in convenient formats prompted the issuance of this pamphlet.

A review of beryllium literature, correspondence with companies, and personal contacts revealed that there was adequate information on beryllium properties, including toxicity, microcracking and twinning. Thus it was decided that this pamphlet would best serve the aerospace industry and its subcontractors by emphasizing machining parameters and minimizing material properties.

1. GENERAL COMMENTS

1.1 THE METAL BERYLLIUM

Beryllium of commercial purity can be considered a complex alloy rather than a pure metal. Although most pure beryllium contains 98 to 99% Be, the following analysis of QMV, Hot Pressed, Hot Rolled or Hot Upset, reveals the complexity of the material:

Be	BeO	Fe	Si	Al	Mg	Mn	Ni	Cr	C
98.9	1.0	0.118	0.03	0.06	0.08	0.09	0.018	0.013	0.12

Beryllium has some excellent qualities such as high strength-to-weight ratio, excellent modulus, high thermal conductivity, low coefficient of thermal expansion, but these are somewhat offset by its generally low ductility. Thus, beryllium's primary usage until only recently has been in the reactor areas and for stable platforms and other components of space guidance systems. Some recent developments in primary fabrication such as vacuum hot pressing, forging and hot rolling, and extruding have shown improvements warranting an increased consideration of beryllium as a structural material.

Beryllium can be obtained from producers in various forms and conditions such as pressed, hot pressed, warm extruded, hot extruded, warm rolled, hot rolled, forgings, high purity castings, etc. These forms are produced from beryllium powder or resintered block. Some typical designations for raw material and worked products which will come to the attention of personnel associated with machinability of beryllium are listed below:

NUCLEAR GRADE -	REACTOR BUILDING GRADE
SP-100-A, SP-200-A, P-100, P-200 -	STANDARD STRUCTURAL GRADES FROM POWDER
I-400, HP-40 -	INSTRUMENT GRADES *(fine grained, min. of 4% BeO)*
PF-20 -	FORGINGS
QMV -	VACUUM HOT PRESSED BLOCK
QMV VACUUM CAST, VC-50 -	COARSE GRAIN RAW CAST MATERIAL
VACUUM CAST DISTILLED, ULTRA-HIGH PURITY -	HIGH QUALITY MATERIAL *(has better than average ductility)*
PR-20 -	ROLLED SHEET

Data available to AFMDC to date indicate that, in most respects, all of the above beryllium products machine similarly. It has been reported that slight improvements in machinability, surface finish and dimensional control were noted on extruded beryllium.

It should be realized that optimum machining conditions can be developed for beryllium, as for other materials, by machinability programs or by a careful study of production machining operations. Therefore, all machining data charts in this report provide starting conditions only.

1.2 GENERAL MACHINING PROBLEMS

Machining of beryllium should not be undertaken without consideration of the following problems:

1.2.1 Toxicity - The Atomic Energy Commission has taken the position that "it is safest to regard beryllium and all its compounds as potentially toxic." Exposure may develop skin reactions and respiratory illness. The latter, called berylliosis, is the most dangerous and is the result of inhalation of beryllium compounds, especially the fluoride or sulfate.

A Materials Advisory Board panel conducted a study on the toxicity of beryllium which later resulted in an Atomic Energy Commission publication, "Recommendations for Control of Beryllium Hazards", August 10, 1951. Standards have since been republished by the Navy (BuAer) and Air Force as Technical Order T.O. 00-80BB-1 (Jan. 10, 1958), and also in "Hygienic Guide" (1958) by the American Industrial Hygiene Association with no changes in the allowable atmospheric concentrations set by AEC in 1951. AEC states "The inplant atmospheric concentration of beryllium should not exceed two micrograms per cubic meter as an average concentration throughout an 8-hour day."

This pamphlet was designed to present machining data on beryllium. Subjects such as toxicity, microcracking, twinning, etc. were included to emphasize their importance and relationship to machining. The Air Force Machinability Data Center will, upon request, furnish references to other documents dealing with the subjects of toxicity and dust control on machining operations.

1.2.2 Twinning and Microcracking - Mechanical working of beryllium in certain machining operations causes twinning as well as microcracking. When beryllium is subjected to high loads in structural applications, these surface changes can cause premature failures.

Studies have disclosed that twinning depths are related to and can be influenced by the type of machining operation, depth of cut, cutting speed, feed, tool geometry and sharpness of cutting tools. These studies have also confirmed that the effects of twinning can be minimized by electrical discharge machining, electrochemical machining or by a series of diminishing depths of cuts followed by removing approximately 0.002 inch from the surface by chemical milling.

1.2.3 Chipout and Spalling - Beryllium is brittle and therefore is prone to chipout, cracking and spalling. These problems have an important bearing on scrappage since the base cost of beryllium is $50-75 per pound and semi-finished components such as gyro platforms have values nearing $1000 per pound.

Companies using beryllium have developed techniques for controlling chipout, cracking and spalling. A few of these techniques are listed as follows:

- Drilling Thin Sheet - One company solved the problem of breakout on the exit side of the holes by sandwiching a thin beryllium sheet between heavier gage sheets of beryllium or mild steel and drilling with very sharp drills. Earlier attempts at sandwiching between aluminum plates resulted in severe cracking.

- Drilling Holes (3 times the diameter and deeper using carbide drills) - A manufacturer of guidance components controlled breakout on the underside of parts by setting a depth stop which allowed only the point of the drill to break through while the drill was under power feed. The stop was then removed, and the drill was fed through by hand.

- Turning Bars - Beryllium tends to chip or break off in pieces as the tool leaves the work. This chipping may be reduced by chamfering both ends of the bar to a diameter slightly larger than the desired finish diameter. One end of the bar may be turned slightly larger than finish diameter for a short distance; then reverse the bar and finish the turning operation.

- Threading on Lathes - Threads should be chased using a single point tool. Thread dies and chasers are not recommended, because beryllium breaks into pieces and jams the tool, causing torn threads and tool breakage.

- Band Sawing - Sawing beryllium produces a heavy burr and rough edge. Enough stock should be allowed on sawed parts for milling, filing or sanding to the finished dimensions.

- End Mill Flaking - End milling flat surfaces on beryllium parts frequently causes surface crazing which produces microcracking. The microcracks are normal to the surface and the depth of the twinned layer. End milled surfaces may show surface damage similar to that which would occur in a material having lamellar defects. Investigations have shown that the material was sound, but surface cracking occurred behind the tool in the direction opposite the feed direction. It was theorized that this 'flaking' was a result of material springback as the compression stresses generated by the tool were relieved. Flaking may be minimized by gradually decreasing the depth of cut for each pass until the finish cut is made.

- Face Mill Flaking - Face milling produces the same type of microcracking as end milling. However, it has been found that face mill defects are more prominent and occur when extreme care is exercised.

- End Mill & Face Mill Breakout - Climb milling should be used when face milling or end milling so that the cutting forces are directed into the material mass. Conventional cutting will tend to cause breakage on entrance and exit of the cutter.

  When end milling a groove through a part, the end mill should be stopped before exiting. The end mill should then be reset to mill from the opposite side.

- Tapping Damage - Tapping is a difficult operation due to the low ductility and high abrasiveness of beryllium. Trained operators are required for this operation.

  A manufacturer of beryllium space guidance components developed a technique to minimize tap breakage and hole breakout. The sequence of operations is as follows:

  1) Rough machine thickness of part to be drilled and tapped; 2) Drill required holes; 3) Countersink drilled holes; 4) Tap the drilled holes; 5) Finish machine thickness of part.

  The above procedure eliminates hole breakout.

Breakout of tapped holes located near the outside edges of flanges on beryllium rings was eliminated by leaving additional stock on both the flange faces and the outside diameter of the flange. The above drilling and tapping procedure was then performed.

1.3 CUTTING FLUIDS

A majority of machine shops are machining beryllium dry. On some machining operations, cutting fluids are beneficial from a standpoint of tool life. A cutting fluid is a necessity for operations such as deep-hole drilling, reaming and tapping. Increased tool life, through the use of cutting fluids, may not be economically justified due to the following considerations:

a) Cutting dry on hooded machines with strong vacuum systems is more efficient than any other method for the control of beryllium fumes and dust in the machining area.

b) Clean beryllium chips have a high reclamation value. It is difficult to clean chips collected from operations where cutting fluids have been used.

c) Evaporation of liquid from the used cutting fluid may leave beryllium dust, which can become a hazard.

Various types of cutting fluids have been used successfully for machining beryllium. The most commonly reported fluid is a soluble oil and water, mixed 1:30 for operations such as turning, drilling, grinding and milling; and approximately 1:20 for operations such as tapping and reaming and others requiring more lubricity than cooling.

Other cutting fluids reportedly being used successfully are:

a) A chemical coolant mixed 1:40 with water for deep-hole drilling, grinding and abrasive cutoff operations.

b) Kerosene was found to be a satisfactory coolant for gun drilling very deep holes. The kerosene was pumped through the drill at 200 psi.

A search for information on adverse effects or reactions on beryllium caused by types of cutting fluids disclosed nothing pro or con. Apparently no extensive studies of a non-proprietary nature have been reported. Data are lacking on possible effects of chlorides or other chemicals causing problems such as stress corrosion, cracking or decreased fatigue strength.

In lieu of any information on detrimental effects resulting from the use of cutting fluids, the Air Force Machinability Data Center recommends that whenever possible beryllium machining be performed dry. When the particular operations require either a coolant or lubricant, the standard types of cutting fluids currently being used for similar operations on cast iron and steel should be satisfactory.

The Air Force Machinability Data Center recommends that fluids used in the machining of highly stressed beryllium structural parts should be evaluated for their effect on surface integrity which in turn could adversely influence structural integrity.

2. MACHINING DATA CHARTS

2.1 TURNING - COMMERCIALLY PURE BERYLLIUM

HARDNESS	75 TO 102 R_B
CONDITION	VACUUM HOT PRESSED FOLLOWED BY ROLLING, FORGING, EXTRUDING, ETC.

OPERATION	TOOL MATERIAL	TOOL GEOMETRY	DEPTH OF CUT in.	FEED ipr	CUTTING SPEED fpm	NOTES
TURNING (ROUGHING OR INTERRUPTED CUTS)	C-1 CARBIDE	BR: 0° SCEA: 15° SR: +6° ECEA: 15° RELIEF: 7° NR: .062"	.100	.015	150	MOST BERYLLIUM MACHINING IS PERFORMED DRY TO FACILITATE CHIP AND DUST REMOVAL. A WATER SOLUBLE OIL MAY BE USED (1:20).
TURNING (FINISH CUTS)	C-2 CARBIDE	BR: -5° SCEA: 15° SR: -5° ECEA: 15° RELIEF: 7° NR: .032"	.002	.005	250	LIGHT DEPTH OF CUTS WILL PREVENT DEEP TWINNING AND MICROCRACKS AS FINAL DIAMETER IS APPROACHED.
TURNING (ROUGHING OR INTERRUPTED CUTS)	T15 HSS	BR: 10° SCEA: 15° SR: 20° ECEA: 6° RELIEF: 6° NR: .032"	.100	.010	65	HIGH SPEED STEEL TOOLS ARE NOT NORMALLY USED FOR TURNING OPERATIONS BECAUSE OF POOR TOOL LIFE DUE TO THE ABRASIVENESS OF BERYLLIUM.
TURNING (FINISH CUTS)	T15 HSS	BR: 10° SCEA: 15° SR: 20° ECEA: 6° RELIEF: 6° NR: .032"	.003 TO .005	.005	65	DEPTH OF CUTS LIGHTER THAN 0.003" WILL CAUSE RAPID TOOL WEAR AND LOSS OF DIMENSIONAL CONTROL BECAUSE OF WORN TOOLS.
TURNING (SEMI-FINISH AND FINISH CUTS)	CERAMIC	BR: -5° SCEA: 15° SR: -5° ECEA: 15° RELIEF: 7° NR: .062"	.002 TO .020 MAX.	.008	300 TO 800	PERMISSIBLE SPEEDS IN THIS RANGE WILL BE GOVERNED BY DUST CONTROL EFFICIENCY. A 32 MICROINCH FINISH CAN BE OBTAINED WHEN A RIGID SETUP IS USED.

2.2 MILLING - COMMERCIALLY PURE BERYLLIUM

HARDNESS	75 TO 102 R_B					
CONDITION	VACUUM HOT PRESSED FOLLOWED BY ROLLING, FORGING, EXTRUDING, ETC.					
OPERATION	**TOOL MATERIAL**	**TOOL GEOMETRY**	**DEPTH OF CUT in.**	**FEED ipt**	**CUTTING SPEED fpm**	**NOTES**
END MILLING	C-2 CARBIDE	UP TO 1/2" DIA. - 2 FLUTE 1/2" DIA. & UP - 4 FLUTE HELIX ANGLE: 15°, RH CUT RR: 10° CA: .030" x 45°	.250	.0006	110	BERYLLIUM TENDS TO CHIP OUT BADLY AS CUTTER LEAVES WORK. SEE PRECAUTIONS STATED IN GENERAL COMMENTS ON END MILL & FACE MILL BREAKOUT.
FACE MILLING (MULTIPLE TOOTH)	C-2 CARBIDE INSERTS	AR: 5° ECEA: 10° RR: 5° CA: .062" x 45° PERIPHERAL RELIEF: 6° END RELIEF: 6°	.100	.008	80	ADEQUATE SUCTION SYSTEMS ARE REQUIRED FOR DUST CONTROL WHERE HEAVY STOCK REMOVAL OPERATIONS ARE USED.
			.010	.003	125	
FACE MILLING (SINGLE TOOTH)	C-2 CARBIDE BRAZED	AR: 0° RR: 8° CR: .062" RAD. PERIPHERAL RELIEF: 7° END RELIEF: 7°	ROUGH .010 MAX.	.005	400	SUCCESSIVELY LIGHTER CUTS ARE RECOMMENDED TO MINIMIZE SURFACE DAMAGE AS FINAL SURFACE IS BEING APPROACHED.
			FINISH .004	.002		
PERIPHERAL MILLING (STAGGER TOOTH SIDE MILL)	M2 HSS	AR: 10° ALTERNATE SHEAR RR: 8° PERIPHERAL RELIEF: 8° CR: .032" RAD.	.010	.003	45	CUTTERS MUST BE VERY SHARP TO PREVENT DAMAGING THE PARENT METAL TOO DEEPLY. LIGHT CUTS PREVENT EDGE BREAKOUT.
			.002	.0015		

2.3 DRILLING - COMMERCIALLY PURE BERYLLIUM

HARDNESS	75 TO 102 R_B					
CONDITION	VACUUM HOT PRESSED FOLLOWED BY ROLLING, FORGING, EXTRUDING, ETC.					
OPERATION	TOOL MATERIAL	TOOL GEOMETRY	HOLE DIAMETER in.	FEED ipr	CUTTING SPEED fpm	NOTES
DRILLING	T15, M33 HSS	118° POINT ANGLE CRANKSHAFT GRIND LIP RELIEF: 6°	UNDER .030	.002	25	HIGH SPEED STEEL DRILLS CAN BE USED FOR LIMITED APPLICATIONS. SMALL HOLES SHOULD BE DRILLED ON SENSITIVE DRILL PRESSES AND FED BY HAND WITH PECKING ACTION.
DRILLING	C-2 CARBIDE SOLID	118° POINT ANGLE CRANKSHAFT GRIND LIP RELIEF: 6° BACK TAPER CLEARANCE: .004/IN.	.030 TO .125	.003	50	DRILL BREAKTHROUGH IS A CRITICAL PROBLEM WITH BERYLLIUM. EXTREME CARE IS REQUIRED TO PREVENT BREAKAGE AND CHIPOUT ON EXIT OF HOLE.
DRILLING	C-2 CARBIDE SOLID OR TIPPED	118° POINT ANGLE CRANKSHAFT GRIND LIP RELIEF: 6° BACK TAPER CLEARANCE: .004/IN.	.125 TO .250	.004	60	CARBIDE TIPPED DRILLS CAN BE USED FOR 1/4" DIAMETER AND LARGER SIZES.
DRILLING	C-2 CARBIDE TIPPED	118° POINT ANGLE CRANKSHAFT GRIND LIP RELIEF: 6° BACK TAPER CLEARANCE: .004/IN.	.250 AND UP	.005	75-100	FOR DEEP HOLE DRILLING IT IS RECOMMENDED THAT THE DRILL SHANK BE 0.010" SMALLER IN DIAMETER THAN THE CARBIDE TIP.

2.4 BAND SAWING - COMMERCIALLY PURE BERYLLIUM

HARDNESS	75 TO 102 R_B				
CONDITION	VACUUM HOT PRESSED FOLLOWED BY ROLLING, FORGING, EXTRUDING, ETC.				
BAND MATERIAL & WIDTH	WORK THICKNESS in.	BAND SPEED fpm	SAWING RATE sq.in./min.	FEED linear in./min.	BAND TYPE
1/4" & ~~1/4"~~ 1/2" HSS*	SHEET UP TO 1/8	500 - 200**	--	50 - 25	32 PITCH, WAVE SET, .025" GAGE
1" HSS(1)	1/8 - 1	150 - 100	15 - 10	120 - 10	10 PITCH, CLAWTOOTH, .040" GAGE x .060" SET
	1 - 3	100 - 85	10 - 5	10 - 1-5/8	6 PITCH, CLAWTOOTH, .040" GAGE x .060" SET
2" HSS(1)	3 - 6	150	10 - 7	3-3/8 - 1-1/8	4 PITCH, CLAWTOOTH, .050" GAGE x .060" SET
	6 - 10	150	7 - 4	1-1/8 - 7/16	2 PITCH, CLAWTOOTH, .050" GAGE x .060" SET
	10 - 20	145 - 125	4 - 1	7/16 - 1/16	2 PITCH, CLAWTOOTH, .050" GAGE x .060" SET
	20 - 30	125 - 100	LESS THAN 1	1/16 & LESS	2 PITCH, CLAWTOOTH, .050" GAGE x .060" SET

* DUE TO HIGH CUTTING PRESSURES A 1/2" WIDE BAND IS RECOMMENDED. WITH CARE, HOWEVER, SAWING CAN BE ACCOMPLISHED USING A 1/4" WIDE BAND.

** SPEEDS ABOVE 500 FT./MIN. HAVE BEEN USED FOR SHEET BERYLLIUM .032" AND THINNER. LIMITATIONS ON SPEED ARE USUALLY DICTATED BY AMOUNT OF DAMAGE (*i.e. cracking or delamination*) WHICH CAN BE TOLERATED.

(1) DATA FROM THE BERYLLIUM CORPORATION
HAZELTON, PENNSYLVANIA

2.5 GRINDING - COMMERCIALLY PURE BERYLLIUM

HARDNESS	75 TO 102 R_B					
CONDITION	VACUUM HOT PRESSED FOLLOWED BY ROLLING, FORGING, EXTRUDING, ETC.					
OPERATION	WHEEL GRADE	WHEEL SPEED fpm	TABLE SPEED fpm	DOWN FEED in./pass	CROSS FEED	NOTES
SURFACE GRINDING (ROUGH)	A24-J5-VBE OR A46-G12-VBE	5500 TO 6500	50 TO 100	.002 MAX.	$\frac{\text{WHEEL WIDTH}}{3}$	* BERYLLIUM IS NONMAGNETIC, THEREFORE IT IS NECESSARY TO CLAMP PARTS ON SURFACE GRINDER TABLE.
SURFACE GRINDING (PRECISION FINISH)	A60-K5-VBE	5500 TO 6500	50 TO 100	.0005 MAX.	.030 IN./PASS MAX.	* PRECISION FINISH SURFACE GRINDING IS GENERALLY USED FOR WORK HAVING SURFACES WHICH REQUIRE LAPPING.
OPERATION	WHEEL GRADE	WHEEL SPEED fpm	WORK SPEED fpm	INFEED in./pass	TRAVERSE work/rev.	NOTES
CYLINDRICAL GRINDING (ROUGH)	A46-G12-VBE	5500 TO 6500	100	.002 MAX.	$\frac{\text{WHEEL WIDTH}}{4}$	SLUDGE WHICH COLLECTS UNDER THE LIQUID IN THE SUMP OR ON THE MACHINE SURFACES SHOULD BE REMOVED FREQUENTLY.
CYLINDRICAL GRINDING (FINISH)	A60-K5-VBE	5500 TO 6500	100	.0005 MAX.	$\frac{\text{WHEEL WIDTH}}{8}$	TELESCOPING TYPE HOODS, POSITIONED FOR MAXIMUM DUST AND MIST COLLECTION, SHOULD BE USED FOR ALL GRINDING OPERATIONS ON BERYLLIUM.

* *Notes in Cylindrical Grinding are also applicable to Surface Grinding.*

2.6 BORING, TREPANNING, REAMING, ROUTING, AND TAPPING - COMMERCIALLY PURE BERYLLIUM

HARDNESS	75 TO 102 R_B					
CONDITION	VACUUM HOT PRESSED FOLLOWED BY ROLLING, FORGING, EXTRUDING, ETC.					
OPERATION	TOOL MATERIAL	TOOL GEOMETRY	DEPTH OF CUT in.	FEED ipr	CUTTING SPEED fpm	NOTES
BORING	C-2 CARBIDE	BR: 0° SCEA: 15° SR: 5° ECEA: 15° END RELIEF: 7° TO 10° SIDE RELIEF: 5° NR: .032"	.075-.150	.010	130	FINE FINISH AND CLOSE TOLERANCE CAN BE ACHIEVED IN BORING BERYLLIUM PROVIDED A RIGID BORING BAR, OF THE LARGEST PRACTICAL DIAMETER, IS USED WITH SHARP CUTTING TOOLS.
			.005-.015	.005	80	
TREPANNING	C-2 CARBIDE	BR: 0° PRIMARY CLEARANCE: 5° SECONDARY CLEARANCE: 7° FRONT, 10° SIDE CHIPBREAKER: .010" x .030"	--	.001 TO .003	100	CORRECT TOOL GEOMETRY CAUSES CHIPS TO BE BROKEN UP INTO FINES FOR EASY REMOVAL THROUGH A VACUUM SYSTEM.
REAMING	C-2 CARBIDE	5 STRAIGHT FLUTES (SEE NOTES)	REAMER DIA. / REAM STOCK ON DIA.: 1/4 .006 1/2 .010 1-1/2 .060	.002	25	MARGIN WIDTHS OF APPROXIMATELY 1/2 THOSE USED FOR STEEL SHOULD BE USED TO REDUCE FRICTION AND GALLING.
ROUTING (SHEET)	C-2 CARBIDE	3/8" TO 1/2" DIAMETER SOLID CARBIDE HELICAL FINE FLUTE, ROTARY FILE TYPE	.050 MAX.	6 IN./MIN. * 3 IN./MIN. **	150	* FOR STACK THICKNESS UP TO .080 IN. ** FOR STACK THICKNESS .080 TO .250 IN. CONVENTIONAL ROUTING ON BERYLLIUM SHEET USING HIGH SPEED SPINDLES IS NOT PRACTICAL WHEN THE ENTIRE CUTTER DIAMETER IS UTILIZED.
TAPPING	M10, M7, M1 HSS	FLUTES: 4 POINT STYLE: STRAIGHT CHAMFER RELIEF: 6° TAP TYPE: PLUG HOOK ANGLE: 0° - 3°	--	--	HAND TAPPING	MACHINE TAPPING IS NOT RECOMMENDED BECAUSE OF THE DIFFICULTY IN TAPPING BERYLLIUM. TAPPED HOLES SHOULD NOT BE PLACED NEAR THE EDGE OF A PART BECAUSE OF POSSIBLE BREAKOUT DUE TO HIGH TORQUE IN TAPPING. SEE GENERAL COMMENTS.

2.7 ELECTRICAL DISCHARGE MACHINING (EDM) - COMMERCIALLY PURE BERYLLIUM

HARDNESS	75 TO 102 R_B
CONDITION	VACUUM HOT PRESSED FOLLOWED BY ROLLING, FORGING, EXTRUDING, ETC.

Electrical Discharge Machining is being utilized very successfully in the fabrication of beryllium components. Due to the high cost per pound of beryllium, substantial savings have been realized by employing EDM as a trepanning operation to salvage large solid blocks from billets or forgings.

BERYLLIUM EDM OPERATIONS SUCCESSFULLY USED:

Cavity sinking, trepanning, small deep holes, odd shapes.

BENEFITS DERIVED FROM USING EDM:

1) On thru holes or openings of odd shapes, breakout and spalling are a critical problem with conventional machining operations. EDM minimizes this problem.

2) Twinning and microcracking, also associated with conventional machining, are minimized.

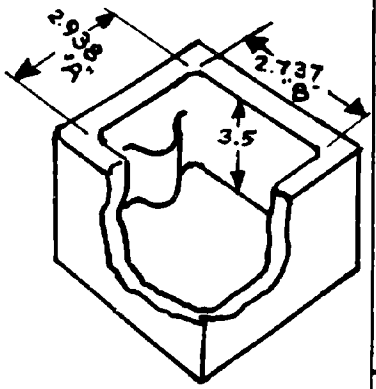
3) EDM provides additional protection against dust since the workpiece is submerged in the dielectric oil during the machining operation.

4) Salvage of large solids which bring much higher reclamation price or can be used for producing small components.

OPERATION	ELECTRODE MATERIAL
Trepanning -	Hard copper was found to have a better wear ratio than half hard brass, in various tube shapes used in trepanning.
Cavity Sinking -	A medium dense graphite cuts faster with less electrode wear and is cheaper than the very dense electrical graphites developed for EDM.
Drilling -	Hard copper tube, half hard brass tube.

Note: DETAILED DATA FOR EDM OF BERYLLIUM IS VERY SCARCE, THUS THE ABOVE INFORMATION IS GIVEN TO SERVE AS A GUIDE AND TO INDICATE THAT EDM IS PRACTICAL.

2.8 ELECTROCHEMICAL MACHINING (ECM) - COMMERCIALLY PURE BERYLLIUM

HARDNESS	75 TO 102 R_B									
CONDITION	VACUUM HOT PRESSED FOLLOWED BY ROLLING, FORGING, EXTRUDING, ETC.									
WORK MATERIAL	CONFIGURATION PRODUCED	POWER SOURCE	ELECTRODE MATERIAL	VOLTS	AMPERES START	AMPERES MAX.	AMPERES END	FLUID / INLET PRESSURE / TEMPERATURE / FLOW RATE / FILTRATION	TOTAL PENETRATION inches / PENETRATION RATE-in./min. / CUTTING TIME minutes / REMOVAL RATE cu. in./min./1000 amp.	DIMENSION AND FLATNESS TOLERANCE inches / FINISH AVER. 4 WALLS rms
TYPE I-400 Be		10,000 AMP.	TYPE 304 STAINLESS STEEL	15	--	2875	--	NaCl 1 LB./GAL.	3.5	±0.010 AVERAGE FLATNESS TIR- 4 WALLS 0.005/0.007
								105/137 PSI (A)	0.042 0.062 (B)	
								96/100°F (A)	65.8	16 TO 32
								--	0.111	
								100 MICRON		
TYPE S-200 Be	WORKPIECE CAVITY	10,000 AMP.	TYPE 304 STAINLESS STEEL	15	--	2875	--	NaCl 1 LB./GAL.	3.5	±0.010 AVERAGE FLATNESS TIR- 4 WALLS 0.005/0.007
	ELECTRODE DIMENSIONS: A - 2.737" B - 2.581"							105/137 PSI (A)	0.042 0.062 (B)	
								90/98°F (A)	67.5	16 TO 32
								--	0.096	
								100 MICRON		

(A) *Lowest for start, buildup to maximum.*

(B) *Lowest for first 0.8 inch, then highest for balance, both constants.*

2.9 CHEMICAL MILLING, CHEMICAL BLANKING OF SHEET AND ELECTROPOLISHING

COMMERCIALLY PURE BERYLLIUM

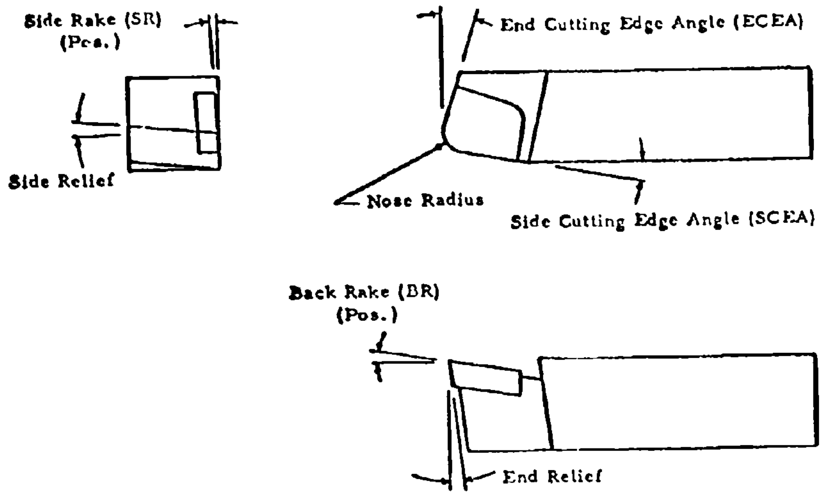
HARDNESS	75 TO 102 R_B			
CONDITION	VACUUM HOT PRESSED FOLLOWED BY ROLLING, FORGING, EXTRUDING, ETC.			
CHEMICAL MILLING & CHEMICAL BLANKING				
PART CLEANING	*Step 1)* VAPOR DEGREASE TO REMOVE LUBRICANTS OR CUTTING FLUIDS. *Step 2)* ALKALINE CLEAN FOR 10 MINUTES MINIMUM IN A SOLUTION OF OAKITE #90 OR EQUIVALENT, 8-10 OZ. PER GAL. AT SOLUTION TEMPERATURE: 160-190°F. *Step 3)* RINSE THOROUGHLY WITH CLEAN FRESH WATER.			
MASKANTS	1) MYLAR ADHESIVE-BACKED TAPE (Minnesota Mining & Mfg. Co. TYPE 150 OR EQUIVALENT). 2) LEAD FOIL ADHESIVE-BACKED TAPE (Minnesota Mining & Mfg. Co. OR EQUIVALENT). 3) CHEM-MILL PRESSURE SENSITIVE TAPE (Minnesota Mining & Mfg. Co. TYPE 3M-Y-9016 OR EQUIVALENT). *Note:* IF CHEM-MILLING SOLUTION TEMPERATURE IS TO BE HIGHER THAN 125°F, A HEAT CURE OF ADHESIVE SHOULD BE MADE AT 250°F UNDER 5 PSI (APPROX.) FOR 3 MINUTES.			
ETCHANTS AND OPERATING CONDITIONS	DULL SURFACE (Rapid Removal)	BRIGHT SURFACE	MATTE SURFACE (Deoxidizing Etch)	REFLECTIVE SURFACE (After Deoxidizing Etch)
	SOLUTION: 10-20% SULFURIC ACID (H_2SO_4) TEMPERATURE: 70° TO 150°F REMOVAL RATE: 0.005 IN./MIN.	SOLUTION: 5% PHOSPHORIC ACID (H_3PO_4) 15% SULFURIC ACID (H_2SO_4) 25% CHROMIC ACID (H_2CrO_4) TEMPERATURE: 70° TO 150°F REMOVAL RATE: 0.0005 IN./MIN.	SOLUTION: 25% NITRIC ACID (HNO_3) 0.25% HYDROGEN FLUORIDE (HF) TEMPERATURE: 70° TO 90°F REMOVAL RATE: 0.0002 IN./MIN.	SOLUTION: CHROMIC ANHYDRIDE (CrO_3) 53.0 g SULFURIC ACID (H_2SO_4) 26.5 cc ORTHOPHOSPHORIC ACID (H_3PO_4) 450.0 cc TEMPERATURE: 75°F REMOVAL RATE: 0.0002 IN./MIN.

ELECTROPOLISHING - BRIGHT MIRROR FINISH

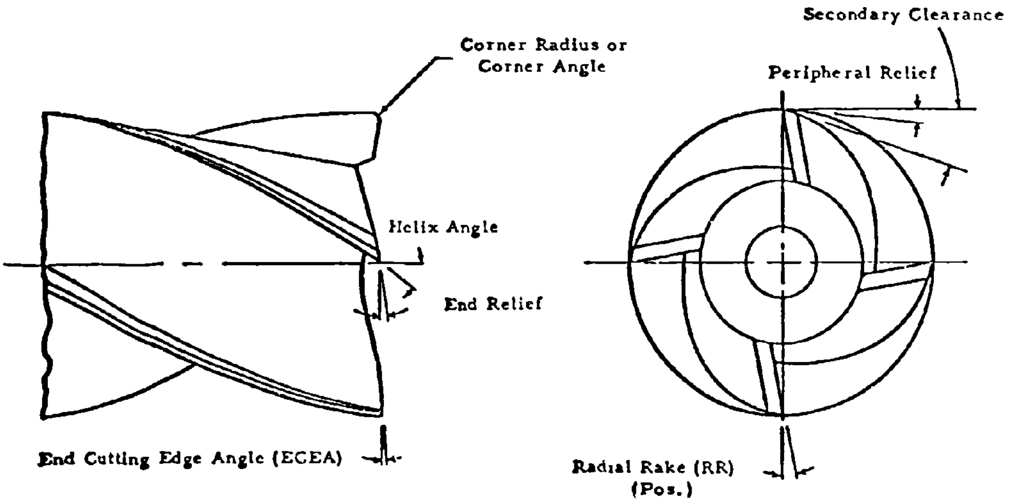
SOLUTION	VOLTS	AMPERES	SOLUTION TEMPERATURE	NOTES
PHOSPHORIC ACID. . . . .100 PARTS SULFURIC ACID . . . . 30 PARTS GLYCEROL . . . . 30 PARTS ABSOLUTE ETHANOL . . . 30 PARTS	2-6	12/SQ. FT.	75°F	PARTS MUST BE RINSED THOROUGHLY IN CLEAN FRESH WATER, AND DRIED.

3. CUTTING TOOL AND GRINDING WHEEL NOMENCLATURE

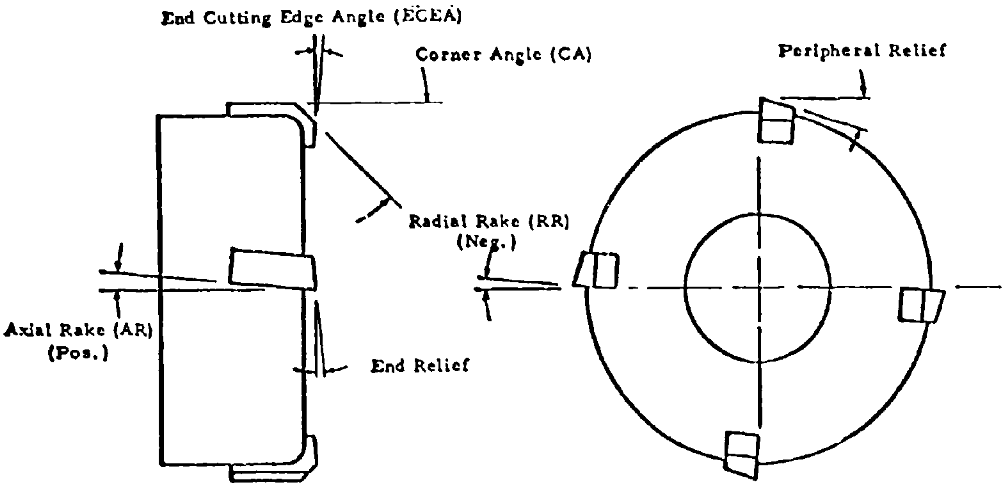
3.1 TURNING



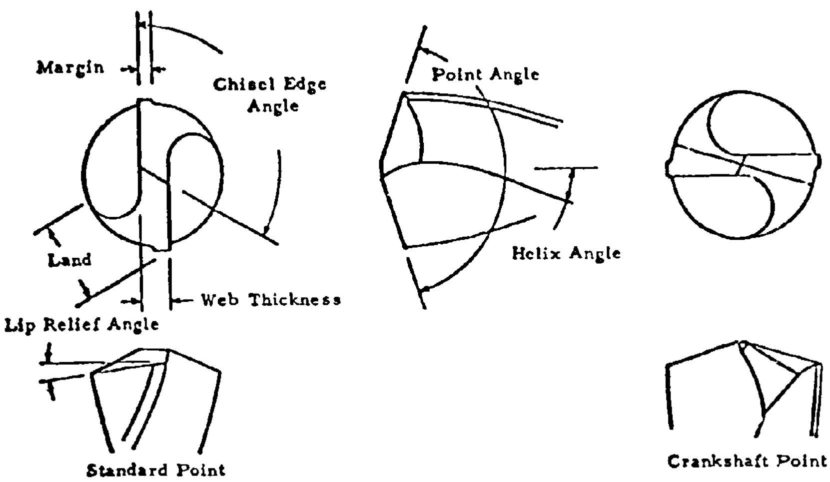
3.2 END MILLING



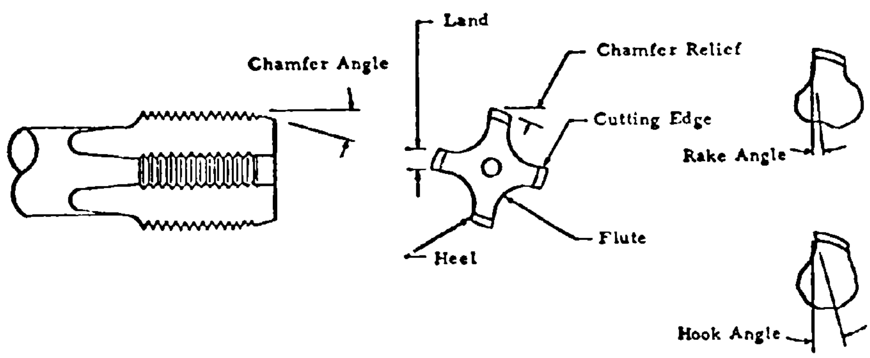
3.3 FACE MILLING



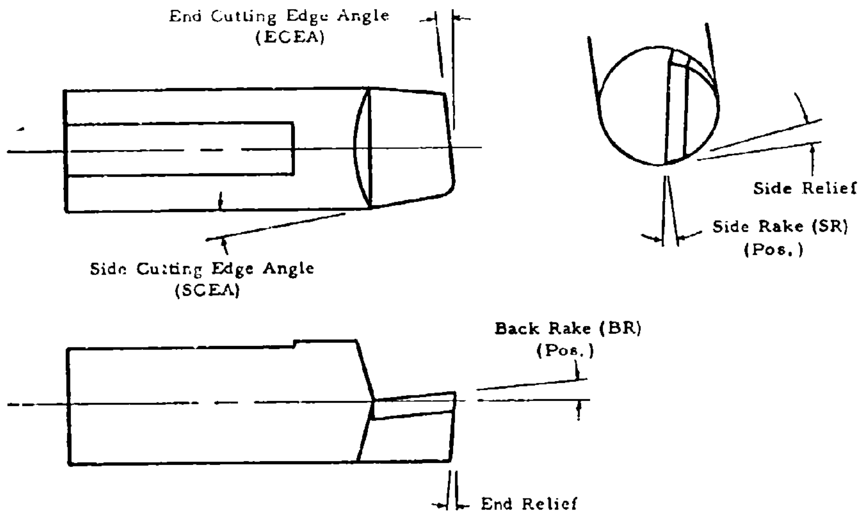
3.4 DRILLING



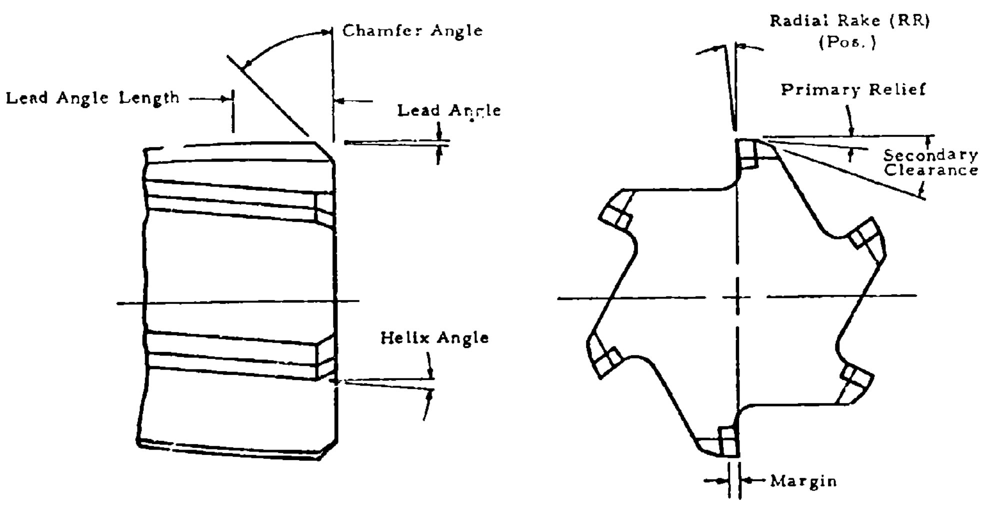
3.5 TAPPING



3.6 CARBIDE PRECISION BORING



3.7 CARBIDE TIPPED REAMERS



3.8 GRINDING WHEEL

STANDARD MARKING SYSTEM CHART*

51	A	36	L	5	V	23
PREFIX	ABRASIVE TYPE	GRAIN SIZE	GRADE	STRUCTURE	BOND TYPE	MANUFACTURER'S RECORD

PREFIX

Manufacturer's symbol indicating exact kind of abrasive *(use optional)*

ABRASIVE TYPE

A - Aluminum Oxide

C - Silicon Carbide

GRAIN SIZE

COARSE	MEDIUM	FINE	VERY FINE
10	36	70	220
12	46	90	240
14	54	90	280
16	60	100	320
20		120	400
24		150	500
		180	600

GRADE

SOFT		MEDIUM		HARD	
A	E	I	M	Q	V
B	F	J	N	R	W
C	G	K	O	S	X
D	H	L	P	T	Y
				U	Z

STRUCTURE

DENSE TO OPEN	
1	9
2	10
3	11
4	12
5	13
6	14
7	15
8	etc.

(use optional)

BOND TYPE

- V - Vitrified
- S - Silicate
- B - Resinoid
- BF - Resinoid Reinforced
- R - Rubber
- RF - Rubber Reinforced
- E - Shellac
- O - Oxychloride

MANUFACTURER'S RECORD

Manufacturer's private marking to identify wheel *(use optional)*

* *American Society of Mechanical Engineer's Standard (ASA B5.17-1958(R1963).*

4. CARBIDE GRADE CHART

C-1 to C-8
MACHINING APPLICATIONS

CARBIDE MANUFACTURERS	INDUSTRY CODE							
	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8
ADAMAS	B	A AM PWX	PWX AA	AAA	DD 5X 434	6X D	7X C 548 Titan 80*	CC Titan 80*
AMCARB	--	D15 D13	--	--	--	--	-	--
BESLY-WELLES	B101	B106 B168	B108	B211	B109 B221	B102	B103 B104 B205 B245	B207 B365*
CARBOLOY	44A	883 860	883 905 895	999 895 320	370 78B	370 78B 78 350	350 78 320	320
CARMET	CA-3	CA-4 CA-443	CA-7	CA-8	CA-610 CA-740	CA-806 CA-720	CA-711	CA-704
COROMANT	H20	H13 H20 H1P	H1P	H05	S6 S4	S2	S1P	F02*
FIRTH-LOACH	FA-5	FA-6	FA-7	FA-8	FT-3 FT-4 FT-5	FT-5 FT-62	FT-6 FT-62	FT-7 FT-72*
FIRTH STERLING	H	HA H-23	HE	HF	T04 NTA	TXH T22	T22 TXL	T31 WF*
FUTURMILL	--	DMC21	--	--	DMC30 DMC32	DMC32	DMC35	--
KENNAMETAL	K1	K6 C8735 K68	K68 K8	K11	KM K21 K2S	K2S K3H K4H K45	K45 K5H K7H	K7H K165*
MULTI METALS	OM1	OM2	OM3	OM4	4M5	--	--	--
NEWCOMER	N10	N20	N30	N40	N50	N60	N70 NM-93*	N80 NM-83* NM-85*
SINTERCAST	Ferro-Tic J	Ferro-Tic J	--	--	Ferro-Tic J	Ferro-Tic J	--	--
SPEEDICUT MITIA	A	B	C	C	TA10 TA5	TTA	TE	TE
TALIDE	C-89	C-91	C-93	C-95	S-880	S-901	S-92 S-900	S-94
TUNGSTEN ALLOY	9	9H	9C	9B	11T 9S 10T	9S 10T 5S	8T 5S	5S
UNIMET	U10	U20	U30	U40	U53	U53 U60	U70 U73	U73 U80 U88*
VALENITE	VC-1	VC-2 VC-22 VC-28	VC-3	VC-4	VC-125 VC-55	VC-125 VC-6	VC-7	VC-8 VC-83* VC-85*
VR/WESSON	2A-68 VR-54	2A-5 VR-54	2A-7	VR-52 2A-7 VR-65*	WS VR-77 VR-89 VR-75	VR-75 WM	VR-73 WH HV VR-65*	HV VP [illegible] VR-[illegible]*
WALMET	WA-141 WA-1 WA-159	WA-2 WA-63 WA-149	WA-35 WA-3	WA-4	WA-86 WA-5	WA-5 WA-6	WA-147 WA-7	WA-8
WENDT-SONIS	CQ12	CQ2	CQ3	CQ4	CY12 CY16	CY16 CY5	CY14 CY2 T18*	CY31 T18*
WICKALOY	N	H	HH	HHH	X7A X7	G8	GX	FX
WILLEY'S	E8	E6	E5	E3	945 8A 10A	8A	606 8A	8AX 509

CAST IRON, NON-FERROUS AND NON-METALLIC MATERIALS

C-1 Roughing
C-2 General Purpose
C-3 Finishing
C-4 Precision Finishing

STEEL AND STEEL ALLOYS

C-5 Roughing
C-6 General Purpose
C-7 Finishing
C-8 Precision Finishing

Listings do not necessarily imply equivalency of various manufacturer's grades.
This chart is not to be considered an endorsement of or an approved list of any manufacturer's products.
**Grades containing more than 50% Titanium Carbide.*

5. IDENTIFICATION AND TYPE CLASSIFICATION OF HIGH SPEED TOOL STEELS

SYMBOL M, MOLYBDENUM TYPES							
TYPE	IDENTIFYING ELEMENTS, IN PER CENT						APPLICATION
	C	W	Mo	Cr	V	Co	
M1	.80	1.50	8.00	4.00	1.00	-	GENERAL PURPOSE
M2	.85	6.00	5.00	4.00	2.00	-	GENERAL PURPOSE
M3 CLASS 1	1.05	6.00	5.00	4.00	2.40	-	FINE EDGE TOOLS
M3 CLASS 2	1.20	6.00	5.00	4.00	3.00	-	FINE EDGE TOOLS
M4	1.30	5.50	4.50	4.00	4.00	-	ABRASION RESISTANT
M6	.80	4.00	5.00	4.00	1.50	12.00	HEAVY CUTS - ABRASION RESISTANT
M7	1.00	1.75	8.75	4.00	2.00	-	FINE EDGE TOOLS - ABRASION RESISTANT
M10	.90	-	8.00	4.00	2.00	-	GENERAL PURPOSE - HIGH STRENGTH
M15	1.50	6.50	3.50	4.00	5.00	5.00	HEAVY CUTS - ABRASION RESISTANT
M30	.80	2.00	8.00	4.00	1.25	5.00	HEAVY CUTS - ABRASION RESISTANT
M33	.90	1.50	9.50	4.00	1.15	8.00	HEAVY CUTS - ABRASION RESISTANT
M34	.90	2.00	8.00	4.00	2.00	8.00	HEAVY CUTS - ABRASION RESISTANT
M35	.80	6.00	5.00	4.00	2.00	5.00	HEAVY CUTS - ABRASION RESISTANT
M36	.80	6.00	5.00	4.00	2.00	8.00	HEAVY CUTS - ABRASION RESISTANT
M41	1.10	6.75	3.75	4.25	2.00	5.00	HEAVY CUTS - ABRASION RESISTANT
M42	1.10	1.50	9.50	3.75	1.15	8.00	HEAVY CUTS - ABRASION RESISTANT
M43	1.25	1.75	8.75	3.75	2.00	8.25	HEAVY CUTS - ABRASION RESISTANT
M44	1.15	5.25	6.25	4.25	2.25	12.00	HEAVY CUTS - ABRASION RESISTANT
SYMBOL T, TUNGSTEN TYPES							
T1	.70	18.00	-	4.00	1.00	-	GENERAL PURPOSE
T2	.80	18.00	-	4.00	2.00	-	GENERAL PURPOSE - HIGHER STRENGTH
T4	.75	18.00	-	4.00	1.00	5.00	HEAVY CUTS
T5	.80	18.00	-	4.00	2.00	8.00	HEAVY CUTS - ABRASION RESISTANT
T6	.80	20.00	-	4.50	1.50	12.00	HEAVY CUTS - HARD MATERIAL
T7	.75	14.00	-	4.00	2.00	-	PLANER TOOLS
T8	.75	14.00	-	4.00	2.00	5.00	GENERAL PURPOSE - HARD MATERIAL
T9	1.20	18.00	-	4.00	4.00	-	EXTREME ABRASION RESISTANT
T15	1.50	12.00	-	4.00	5.00	5.00	EXTREME ABRASION RESISTANT

GENERALLY ALL OF THE ABOVE HIGH SPEED STEELS ARE MANUFACTURED BY THE FOLLOWING COMPANIES:

ALLEGHENY LUDLUM STEEL CORPORATION
BETHLEHEM STEEL CORPORATION
BRAEBURN ALLOY STEEL DIVISION, CONTINENTAL COPPER & STEEL INDUSTRIES, INC.
THE CARPENTER STEEL COMPANY
COLUMBIA TOOL STEEL COMPANY
CRUCIBLE STEEL COMPANY OF AMERICA
FIRTH STERLING, INC.
JESSOP STEEL COMPANY
LATROBE STEEL COMPANY
H. K. PORTER COMPANY, INC., VULCAN-KIDD STEEL DIVISION
SIMONDS SAW AND STEEL COMPANY
UNIVERSAL-CYCLOPS STEEL CORPORATION
VANADIUM-ALLOYS STEEL COMPANY, DIVISION OF VASCO METALS CORPORATION

HIGH SPEED STEELS M41 THROUGH M44 ARE MADE BY:

M41 - CRUCIBLE STEEL COMPANY OF AMERICA
M42 - VANADIUM-ALLOYS STEEL COMPANY, DIVISION OF VASCO METALS CORPORATION
M43 - LATROBE STEEL COMPANY
M44 - BRAEBURN ALLOY STEEL DIVISION, CONTINENTAL COPPER & STEEL INDUSTRIES, INC.

This chart is not to be considered an endorsement of any manufacturer's product or an approved list of any manufacturer's products.

6. ROCKWELL-BRINELL - ULTIMATE TENSILE STRENGTH HARDNESS CONVERSION CHART

ROCKWELL C to BRINELL 3000 KG.

For hardened steel and alloys

ROCKWELL C 150 Kg. Load "Brale"	BRINELL 3000 Kg. Load 10 mm Ball
60	614
59	600
58	587
57	573
56	560
55	547
54	534
53	522
52	509
51	496
50	484
49	472
48	460
47	448
46	437
45	426
44	415
42	393
40	372
38	352
36	332
34	313
32	297
30	283
28	270
26	260
24	250
22	240
20	230
-	-

BRINELL 3000 KG. TO ULTIMATE TENSILE STRENGTH FOR STEELS

BRINELL 3000 Kg. Load 10 mm Ball	ULTIMATE TENSILE STRENGTH, psi
200	100,000
225	108,000
250	122,000
275	141,000
300	158,000
325	174,000
350	188,000
375	202,000
400	215,000
425	227,000
450	238,000
475	249,000
500	258,000
525	267,000
550	282,000
575	295,000
600	308,000

ROCKWELL B to BRINELL 500 and 3000 KG.

For unhardened steel, steel of soft temper, gray and malleable cast iron and most nonferrous metal

ROCKWELL B 100 Kg. Load 1/16" Dia. Ball	BRINELL 500 Kg. Load 10 mm Ball	BRINELL 3000 Kg. Load 10 mm Ball
100	201	240
99	195	234
98	189	228
97	184	222
96	179	216
95	175	210
94	171	205
93	167	200
92	163	195
91	160	190
90	157	185
89	154	180
88	151	176
87	148	172
86	145	169
85	142	165
84	140	162
83	137	159
82	135	156
81	133	153
80	130	150
79	128	147
78	126	144
77	124	141
76	122	139
75	120	137
74	118	135
72	114	130
70	110	125
68	107	121
66	104	117
64	101	114
62	98	110
60	95	107
58	92	104
56	90	101
54	87	-
52	85	-
50	83	-
48	81	-
46	79	
44	78	
42	76	
40	74	
38	73	
36	71	
34	70	
32	68	
30	67	
28	66	
24	64	
20	62	
16	60	
12	58	
8	56	
4	55	
0	53	

7. DESCRIPTION OF AFMDC

AIR FORCE MACHINABILITY DATA CENTER, 3980 Rosslyn Drive, Cincinnati, Ohio 45209. Operated for the Air Force Materials Laboratory, Manufacturing Technology Division, under Contract AF 33(615)-5262, by Metcut Research Associates Inc.

SCOPE

The Air Force Machinability Data Center (AFMDC) collects, evaluates, stores, and disseminates material removal information including specific and detailed machining data for the benefit of industry and government. Strong emphasis is given to engineering evaluation for the purpose of developing optimized material removal parameters, such as speeds, feeds, depths of cut, tool material and geometry, cutting fluids and other significant variables. Data are being processed for all types of materials and for all kinds of material removal operations such as turning, milling, drilling, tapping, grinding, electrical discharge machining, electrochemical machining, etc.

COLLECTION

AFMDC has a mechanized system in which punch cards are used to store and retrieve all types of material removal information including all significant numerical data. Early in 1966, a new low-cost computer will be used for storing and processing data from a master card and disk file and for computer decoding. The focal concept for acquisition, interrogation, or presentation of information is the specific material (with definite chemical, physical, or mechanical properties) and the specific material removal operation being used. When necessary, card source control copies may be used to retrieve original documents which are in document storage at AFMDC.

INFORMATION SERVICES

AFMDC places strong emphasis on providing specific and detailed answers to technical inquiries in the field of material removal. A User File, consisting of important users in the field of material removal, has been developed to receive information products including machining data pamphlets and tables on materials of current interest, state-of-the-art reports, technical announcements, and other appropriate items. Services are available without charge to the aerospace industry, Department of Defense (including all of the military services and their contractors), and other government agencies, technical institutions, and non-military industries in a position to assist the defense effort.

TO REQUEST MACHINING INFORMATION . . . .

Telephone:	513-271-9510
TWX:	513-577-1785 *or*
Write:	Air Force Machinability Data Center 3980 Rosslyn Drive Cincinnati, Ohio 45209

TO HELP US ANSWER YOUR INQUIRY, IF POSSIBLE PLEASE:

1. Identify the material being machined *(specification or tradename)*; condition, *(as cast, hot rolled, cold drawn, annealed, quenched and tempered, etc.)*; microstructure and hardness.
2. Identify the material removal operation in question *(turning, milling, drilling, tapping, surface grinding, electrical discharge machining (EDM), electrochemical machining (ECM), etc.)*.
3. Specify reasons for requiring data unless your needs are proprietary. This enables AFMDC to broaden the scope of its technical advice.
4. Specify delivery requirements.
5. Indicate to whom the inquiry reply should be sent.
6. Transmit all details concerning present practices, including feeds, speeds, cutting tool material and geometry, cutting fluids, etc., in the event your inquiry pertains to improvement of an existing machining situation.

****

NOTE: *Association of the names of companies and individuals with specific requests is kept confidential. However, data developed remain the property of AFMDC for dissemination as required for answering similar inquiries and for developing data products.*

Unclassified

Security Classification

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3. REPORT TITLE

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10. AVAILABILITY/LIMITATION NOTICES Qualified requesters may obtain copies of this report from DDC. This document is subject to export-controls and each transmittal to foreign governments or foreign nations may be made only with prior approval of the Air Force Materials Laboratory (MATF).

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Manufacturing Technology Division Air Force Materials Laboratory Wright-Patterson Air Force Base

13. ABSTRACT

This report contains evaluated machining information for beryllium which has been extracted from many sources. Machining data are tabulated and presented in chart form for the following processes: Turning, Milling, Drilling, Band Sawing, Grinding, Boring, Trepanning, Reaming, Routing, Tapping, Electrical Discharge Machining, Electrochemical Machining, and Chemical Machining. Also included is a General Comment Section dealing with the problems associated with beryllium machining, such as twinning, microcracking, toxicity, chipout and spalling, and cutting fluids.

DD FORM 1 JAN 64 1473

Unclassified

Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Machining Data						
Grinding Data						
Electrical Discharge Machining Data						
Electrochemical Machining Data						
Chemical Machining Data						
Toxicity						
Microcracking						
Twinning						
Beryllium						
Aerospace Alloy						
Chipout						
Spalling						

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